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Effects of Mild Head Injury on Postural Stability as Measured Through Clinical Balance Testing

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Objective: Although force-platform measures of postural stability provide objective information concerning mild head injury (MHI) resolution, their application has remained limited due to the high costs and impracticality for sideline use. Therefore, we investigated the efficacy of a clinical balance testing procedure for the detection of acute postural stability disruptions after MHI.

Design and Setting: We used a posttest control group design with repeated measures. Postural stability was tested at 3 postinjury time intervals (days 1, 3, and 5) using 2 procedures in a sports medicine laboratory: 1) a clinical balance battery consisting of 3 stances (double leg, single leg, and tandem) on 2 surfaces (firm and foam), and 2) the Sensory Organization Test using a sophisticated force-platform system.

Subjects: Sixteen MHI and 16 matched control subjects participated in this study.

Measurements: We measured performance with the Balance Error Scoring System for each of the clinical balance tests and the NeuroCom Smart Balance Master for Sensory Organization Testing.

Results: We found significantly higher postural instability in the MHI subjects revealed through the clinical test battery, with the 3 stances on the foam surface eliciting significant differences through day 3 postinjury. Results of the Sensory Organization Test revealed significant group differences on day 1 postinjury.

Conclusions: Our results revealed that the Balance Error Scoring System may be a useful clinical procedure to assist clinicians in making return-to-play decisions in athletes with MHI in the absence of force-platform equipment.

Key Words: concussion, postural equilibrium, postural control

Mild head injury (MHI) represents one of the most challenging pathologies facing sports medicine personnel. The complexity of the brain and the few objective signs often manifested at the time of injury contribute to the difficulty surrounding MHI assessment. In the absence of loss of consciousness, sports medicine personnel are left to depend upon subjective symptoms reported by the athlete. Return-to-play decisions in these circumstances are often based on speculation rather than certainty. The potential result of prematurely returning an athlete to competition after MHI can be catastrophic; the incidence and danger of second-impact syndrome are well documented in the literature.[1-5] Of less concern, but still worthy of consideration, is the possible risk of predisposition to other injuries during activities that alter sensory input to 1 or more sensory systems.[6] Thus, the need for development of objective measures that can be used during both sideline and clinical assessments is substantial.

Postural control has been proved to be an objective measure in the evaluation of acute MHI.[6-8] Guskiewicz et al[7] demonstrated increases in postural sway in athletes with MHI using a modified Clinical Test of Sensory Interaction and Balance protocol. The decreases in postural stability persisted for up to 3 days after injury in comparison with control subjects and were most evident when the subjects were standing either on a foam or a moving (tilting) surface. In a similar manner, decreases in postural stability have been reported for up to 3 days postinjury using the Sensory Organization Test (SOT) on the NeuroCom Smart Balance Master (NeuroCom International, Inc, Clackamas, OR).[6,8] Again, differences between MHI and control subjects became most evident when visual and support surface conditions were altered. MHI subjects demonstrated increased postural instability under altered environmental conditions, suggesting that MHI causes a transient sensory interaction problem.

Both the modified Clinical Test of Sensory Interaction and Balance and the SOT used in the above studies require sophisticated force-plate systems that provide a means to challenge several of the sensory modalities involved in balance by altering visual and support surface conditions. Neither of these force-plate systems is readily available to clinicians making MHI assessments.

The Balance Error Scoring System (BESS) was developed as a method of evaluating postural stability without the use of complex or expensive equipment.[9] Significant correlations between the BESS and force-platform sway measures using normal subjects have been established for 5 static balance tests (single-leg stance on a firm surface, tandem stance on a firm surface, double-leg stance on a foam surface, single-leg stance on a foam surface, and tandem stance on a foam surface), with intertester reliability coefficients ranging from 0.78 to 0.96.[9]

The purpose of our study was to investigate several potential objective balance tests that could be conducted in the athletic arena to assist in the assessment of MHI without the use of computerized force-platform equipment. Specifically, we com-

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pared balance performance in MHI and control subjects using a battery of clinical balance tests to try to identify the test variations that would best elicit postural unsteadiness after MHI. Additionally, we administered the SOT to determine whether the results of the clinical balance tests paralleled the results obtained with the force-plate system. We hypothesized that the single-leg and tandem stances on the foam surface, coupled with the increased measurement sensitivity afforded by the BESS, would best elicit postural unsteadiness after MHI. Further, we hypothesized that the results obtained in these 2 clinical tests would parallel those of the SOT.

METHODS

Subjects

Sixteen athletes (15 men, 1 woman: age = 19.2 ± 2.3 years, height = 183.1 ± 10.0 cm, weight = 84.3 ± 18.6 kg) who sustained an MHI either during practice or competition were assessed on days 1, 3, 5, and 10 postinjury. Cervical spine pathology in all subjects had been ruled out by attending certified athletic trainers or team physicians, or both, before each subject entered the study. MHI was defined according to the 4 criteria provided by Rimel et al,[10] which includes a Glascow coma scale score greater than 12, fewer than 20 minutes of unconsciousness, hospitalization for fewer than 48 hours, and negative findings on neuroimaging. This definition encompasses grade I and II concussions according to the Cantu scale.[11] Additionally, 16 matched control subjects (15 men, 1 woman: age = 22.5 ± 2.3 years, height = 183.1 ± 9.0 cm, weight = 88.7 ± 17.5 kg) were recruited from the intramural sports program and assessed according to the same schedule. Control subjects were matched on the basis of sex, age, height, and weight. No subjects in either group had sustained either a musculoskeletal injury that could have affected their ability to balance or a head injury within the previous year. We screened all subjects for pre-existing visual, vestibular, and balance disorders by asking about any previously diagnosed conditions. Each subject signed an informed consent form approved by the institutional review board at the University of North Carolina at Chapel Hill after being advised of the purposes and methods of the study.

Procedures

At each testing session, we evaluated subjects with both a clinical test battery and the SOT using the NeuroCom Smart Balance. The order of testing was randomized between subjects and testing sessions postinjury. In addition to the postural stability testing, subjects were questioned at each testing session from a standard list about the presence of signs and symptoms commonly associated with MHI.

Clinical test battery. Three different stances (double, single, and tandem) were tested twice, once on a firm surface and once on a 10-cm-thick piece of medium-density foam (45 cm^2 × 13 cm thick, density = 60 kg/m^3, load deflection = 80 to 90) for a total of 6 trials. The nondominant leg was used as the stance limb during the single-leg trials and was placed in the rear position during the tandem stances. Leg dominance was defined as the preferred leg to use while kicking a ball. The order of the clinical tests was randomized between subjects and session, with each test lasting 20 seconds. After each subject, the foam was rotated 90° to prevent it from wearing unevenly over many trials. We asked subjects to assume the required

Figure 1. Subjects performed each clinical test with their eyes closed and hands on their iliac crest. A, Double-leg stance; B, single-leg stance; C, tandem stance on the firm surface.

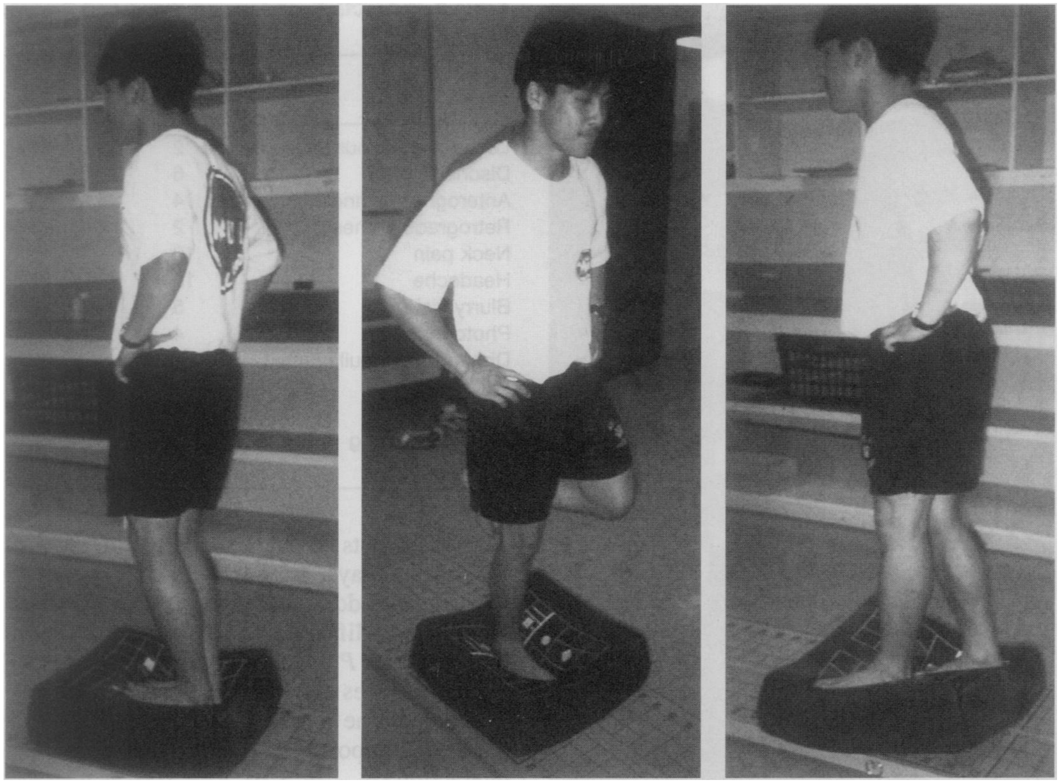

Figure 2. A, Double-leg stance; B, single-leg stance; C, tandem stance on the foam surface.

Table 1. Balance Error Scoring System*

Errors
Lifting hands off the iliac crests
Opening the eyes
Stepping, stumbling, or falling
Moving the hip into more than 30° of flexion or abduction
Lifting the forefoot or heel
Remaining out of the testing position for more than 5 s

*The BESS score is calculated by adding 1 error point for each error.

stance by placing their hands on their iliac crests and told them that the test would begin when they closed their eyes. During the single-leg stances, subjects were asked to maintain the contralateral limb in 20° of hip flexion and 40° of knee flexion. Additionally, we asked subjects to stand quietly and as motionless as possible in the stance position, keeping their hands on their iliac crests and their eyes closed (Figures 1 and 2). Subjects were told that upon losing their balance, they were to make any necessary adjustments and return to the testing position as quickly as possible. Performance was scored by adding 1 error point for each error committed (Table 1). Trials were considered incomplete if subjects could not sustain the stance position for longer than 5 seconds, and these trials were assigned standard maximum scores.[9] This method of testing has been previously described in detail and has been shown to be both valid and reliable using normal subjects.[9]

Sensory Organization Test. The SOT is designed to systematically disrupt the sensory selection process by altering the orientation information available to the somatosensory or visual inputs (or both) while measuring a subject's ability to maintain equilibrium (Figure 3). The test protocol consists of 3 20-second trials under 3 different visual conditions (eyes open, eyes closed, sway referenced) and 2 different support surface conditions (stable, sway referenced). This testing series involves 18 trials overall. The term "sway referencing" refers to the tilting of the support surface or visual surround, or both, to directly follow the subject's center of gravity such that the orientation of the surface remains constant in relation to the center of gravity angle. By using this technique, the somatosensory or visual systems (or both) perceive that the subject's orientation to gravity is constant when in fact it is changing, requiring the subject to ignore the inaccurate information from the sway-referenced sense(s). The composite equilibrium score describing a person's overall level of performance during all the trials in the SOT is calculated, with higher scores being indicative of better balance performance. A full description of the administration and interpretation of the SOT, including the calculation of the equilibrium score, has been published.[12] Validity of the SOT is supported by studies demonstrating correlations between balance impairments as measured by the SOT and other testing and survey instruments in patients with MHI, stroke, and balance or dizziness disorders.[6,13–15] Of particular interest is the fact that the SOT has been reported to distinguish with high reliability among normal individuals, individuals with known vestibular pathology, and individuals suspected of exaggerating symptoms.[16,17]

Data Analysis

We analyzed error scores from the clinical test battery using a repeated-measures analysis of variance (ANOVA) with group as a between-subject factor and day, stance, and surface as within-subject factors. Additionally, we conducted a repeated-measures ANOVA with group as a between-subject factor and day as a within-subject factor on the SOT composite scores to determine group differences. Statistical significance of $P <$

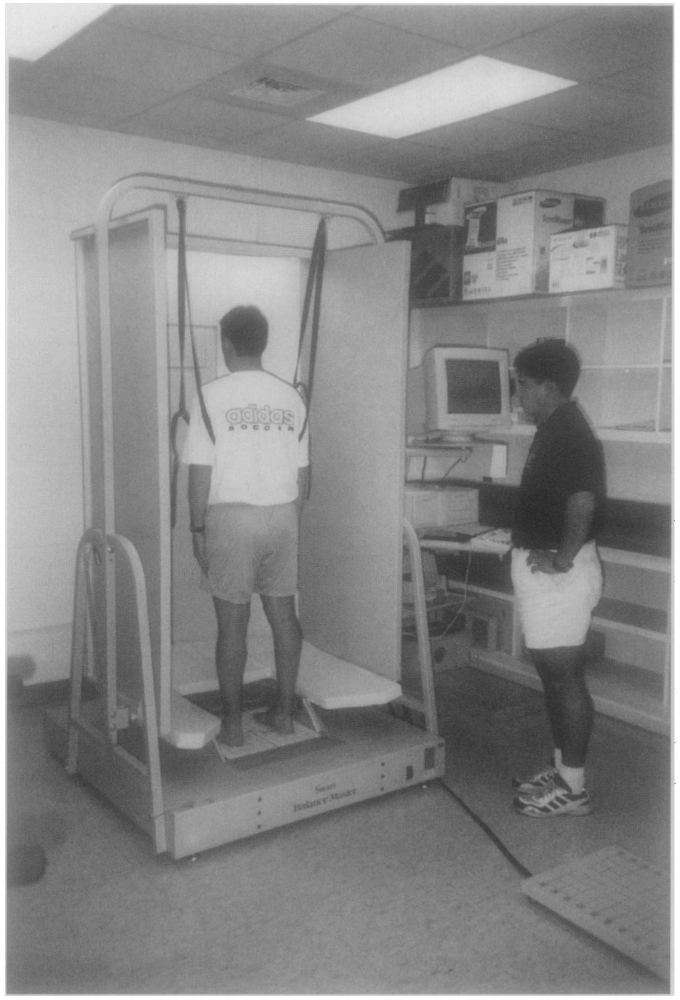

Figure 3. The NeuroCom Smart Balance Master allows for sensory organization testing using a dual force-plate system. Both the support surface and visual surround tilt (sway referencing) to alter sensory conditions.

.05 was set a priori for the ANOVA analyses. Multiple paired *t* tests were performed on day 1 scores to identify the tests most sensitive to postural instability after MHI. To avoid the problem associated with inflated error rates from the multiple tests, we considered results significant only at the .01 level. This level was obtained by dividing .05 by the number of tests, according to the Bonferroni method.[18]

RESULTS

Of the 16 subjects with MHI, 9 had lingering symptoms lasting up to 3 days postinjury, and only 2 subjects complained of symptoms lasting up to 5 days postinjury (Table 2). Repeated-measures ANOVA on the error scores for each test and surface (Tables 3 and 4) revealed the following significant interactions: group × day × surface ($F_{2,60}$ = 3.73, *P* = .03), group × day × stance ($F_{4,120}$ = 3.76, *P* = .01), group × surface ($F_{1,30}$ = 9.69, *P* = .00), and group × day ($F_{2,60}$ = 8.92, *P* = .00). Main effects for group ($F_{1,30}$ = 6.01, *P* = .02), day ($F_{2,60}$ = 4.85, *P* = .01), surface ($F_{1,30}$ = 141.62, *P* = .00), and stance ($F_{2,60}$ = 121.46, *P* = .00) were also significant. Tukey post hoc analysis of the group × day × surface interaction (Tukey honestly significant difference [HSD] = 1.55) demonstrated higher error scores by MHI subjects in comparison with control subjects on day 1 postinjury on the firm surface (Figure 4) and on days 1 and 3 postinjury on the foam surface (Figure 5). Additionally, the multiple paired *t* tests revealed significant differences between groups for double-leg (t_{15} = −3.10, *P* = .01), single-leg (t_{15} = −3.11, *P* = .01), and tandem stances (t_{15} = −4.01, *P* = .00) on a foam surface (Figure 6). The repeated-measures ANOVA we conducted on the SOT composite scores revealed a significant group × day interaction ($F_{2,60}$ = 3.70, *P* = .03), as well as significant main effects for group ($F_{1,30}$ = 7.05, *P* = .01) and day ($F_{2,60}$ = 22.88, *P* = .00). Tukey post hoc analysis (Tukey HSD = 5.28) revealed that MHI subjects demonstrated increased postural instability as measured by the SOT composite equilibrium score on day 1 postinjury when compared with the control group and their own day 3 postinjury scores (Figure 7).

Table 2. Subjects Experiencing Signs and Symptoms After MHI (*n* = 16)

	Day of Injury	Day 1 Postinjury	Day 3 Postinjury
Loss of consciousness	2		
Disorientation	6		
Anterograde amnesia	4	2	
Retrograde amnesia	2	1	
Neck pain	10	7	4
Headache	15	14	5
Blurry vision	5	2	
Photophobia	4	2	
Dizziness/disequilibrium	7	3	
Fatigue	4	5	
Sleepiness	5	2	2
Nausea/vomiting	3	1	
Tinnitus	2		

DISCUSSION

Under normal circumstances, a person balances by integrating sensory information from the visual, vestibular, and somatosensory systems. This information is used to select appropriate motor responses for the maintenance of postural equilibrium. If the information from 1 system is deficient or altered, the information from the other systems should compensate and allow the individual to remain in static postural equilibrium. Athletes sustaining MHI have been reported to exhibit sensory interaction problems, whereby they are unable to ignore altered sensory information, resulting in the selection of improper motor responses for up to 3 days postinjury.[6–8] Thus, information concerning MHI may be best obtained through postural control assessments under altered somatosensory and visual sensory conditions.

The most significant finding in our investigation was the identification of a clinical balance testing battery sensitive to acute postural stability disruptions after MHI. Significant group differences on day 1 postinjury were revealed using the BESS with the single-leg, double-leg, and tandem stances on a foam surface. The results of the SOT composite scores paralleled the results revealed with the clinical balance tests and are similar to those noted in our previous investigation.[6]

The resolution of signs and symptoms recorded across the 3 postinjury testing sessions appears to coincide with the postural stability recoveries demonstrated by the MHI subjects (Table 2; Figures 4, 5, and 7). Signs and symptoms are suspected by clinicians to be underreported in many situations. Assuming

Table 3. Error Scores (Mean ± SD) by Day Postinjury for Test and Surface

	Day 1		Day 3		Day 5	
Stance/Surface	MHI	Control	MHI	Control	MHI	Control
Double/firm	.1 ± .3	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Single/firm	2.6 ± 1.9	1.9 ± 1.5	1.9 ± 1.5	1.9 ± 1.7	2.5 ± 2.5	1.8 ± 2.0
Tandem/firm	1.5 ± 1.8	.4 ± .5	.8 ± 1.3	.5 ± .9	.6 ± 1.0	.8 ± 1.1
Double/foam	.6 ± .8	0 ± 0	.2 ± .5	.1 ± .3	.3 ± .7	.1 ± .3
Single/foam	7.8 ± 3.8	4.3 ± 1.5	5.2 ± 2.6	4.5 ± 3.1	5.3 ± 2.7	4.4 ± 1.2
Tandem/foam	4.6 ± 2.6	1.7 ± 1.6	3.7 ± 2.9	1.6 ± 1.5	2.6 ± 2.0	2.4 ± 1.4

Table 4. Total Error Scores (Mean ± SD) by Day Postinjury and Surface

	Day 1		Day 3		Day 5	
Surface	MHI	Control	MHI	Control	MHI	Control
Firm	4.3 ± 3.0	2.3 ± 1.9	2.6 ± 2.4	2.4 ± 2.3	3.2 ± 3.1	2.6 ± 2.9
Foam	13.1 ± 6.6	6.1 ± 2.1	9.2 ± 5.3	6.3 ± 3.4	8.2 ± 4.4	6.9 ± 2.0

that the subjects were accurate in reporting signs and symptoms, our results justify consideration of subjective information in combination with postural stability measures.

Our results failed to reveal significant differences between MHI and control subjects using the double-leg, single-leg, and tandem stances on a firm surface. The double-leg balance test, often referred to as the Romberg test, has been previously advocated for use in MHI assessment.[19–21] A potential reason for the failure of the tests involving the 3 stances on a firm surface to elicit postural instability after MHI may be that the balance task failed to challenge the postural control system of conditioned athletes. Clinicians should be cautious in relying on these tests to elicit postural instability during acute MHI assessments.

From a statistical perspective, post hoc analysis of the group × day × surface interaction revealed significant differences for both surfaces on day 1 postinjury (Figures 4 and 5). The differences in postural stability between groups, however, were more pronounced and clinically relevant for all 3 stances using the foam surface on day 1 postinjury. Supporting this statement are the results of the *t* tests on the day 1 error scores. Again, all 3 stances on the foam surface elicited significantly higher postural instability in the MHI subjects (Figure 6). Our previous work using an identical test battery and methodology with normal subjects has suggested that overall balance performance is best described from a battery of tests, rather than 1 specific test.[9] Based on those findings and the results of our current investigation, we recommend clinicians consider using a battery of tests to assess postural instability rather than relying solely on any 1 test. Specifically, we recommend using the 3 stances on a foam surface during MHI assessments.

We attribute the decreased postural stability during the foam test battery to the sensory interaction and processing problems previously demonstrated in MHI subjects during the first few days after injury.[6–8] The single-leg and tandem stances, along with the foam surface, diminish the amount of somatosensory information available to the postural control system. These factors, plus the elimination of visual inputs, may present enough of a challenge to the central sensory integration and processing mechanisms to elicit deficits resulting from MHI. Adjunct maneuvers performed during the various stances on foam may further challenge the postural control system and help clinicians in their evaluations. Such tasks include finger-to-nose coordination movements and maintenance of the head and neck in varying degrees of flexion, extension, or rotation.

Knowing whether improvements in performance over repeated trials are related to increases in test familiarity or improvements in an underlying deficiency represents an important aspect of clinical evaluation techniques. Our previous work with this test battery in normal subjects failed to reveal performance improvements over repeated exposures, as measured through the BESS during identical between-assessment intervals.[9] Clinicians using these procedures, therefore, can be confident that improvements across days 1, 3, and 5 postinjury represent resolution of the postural instability after MHI. Further research is needed to determine whether learning effects occur during shorter between-test time intervals.

Significant group differences with the foam surface were revealed on both days 1 and 3 postinjury, whereas the SOT results revealed significant group differences only on day 1 postinjury. This is consistent with other findings, whereby balance deficits resolve before day 3 postinjury.[6,7] We speculate that the discrepancy between the foam surface and SOT results may be related to several factors. First, the SOT involves altered sensory conditions while the subject remains in a double-leg stance, whereas 3 different stances (single, double, and tandem) constitute the results on the foam surface. Although both tests, the SOT and the 3 stances on foam, are focused on assessing postural stability, they may evaluate different aspects of postural control. This idea is supported by the lack of significant correlations between SOT composite scores and performance in the 3 stances on the foam surface in normal individuals.[22] Additionally, the differences between the SOT and foam surface results may be related to the scales of measurement associated with the 2 tests. The range of composite scores is larger than the error scores, possibly rendering the latter less sensitive and, therefore, less likely to be significant.

An ideal evaluation procedure allows clinicians to distinguish pathologic from normal results based on a current assessment. We use the evaluation of a suspected anterior cruciate ligament lesion as an example. As part of the assessment, clinicians can compare the laxity of the involved knee with that of the contralateral knee. In addition, experienced clinicians often have a "feeling" of normal laxity and endstop quality they can compare. In the case of MHI, bilateral

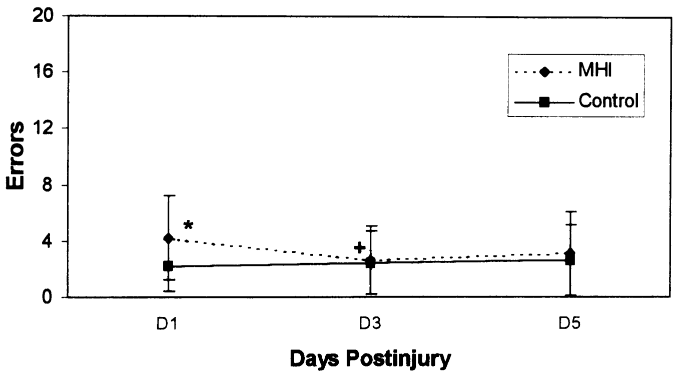

Figure 4. Error score means (±SD) for the 3 stances on the firm surface for each testing session (day 1 postinjury through day 5 postinjury). Asterisk indicates significant difference from other group; +, significant difference from day 1 test. Tukey HSD = 1.55, *P* < .05.

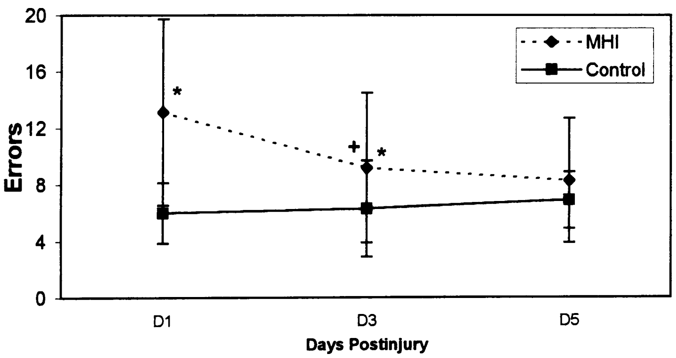

Figure 5. Error score means (±SD) for the 3 stances on the foam surface for each testing session (day 1 postinjury through day 5 postinjury). Asterisk indicates significant difference from other group; +, significant difference from day 1 test. Tukey HSD = 1.55, *P* < .05.

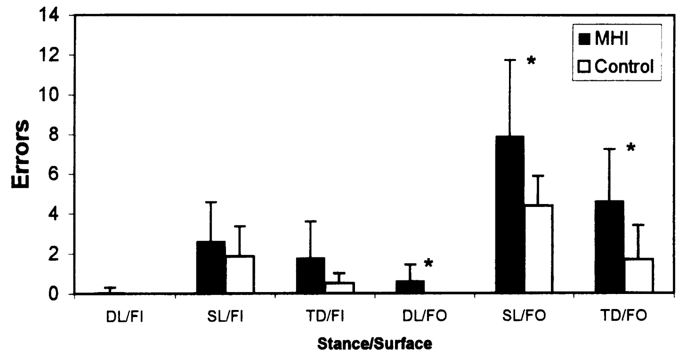

Figure 6. Error score means (±SD) for the 3 stances on both surfaces on day 1 postinjury (DL, double-leg stance; SL, single-leg stance; TD, tandem stance; FI, firm surface; FO, foam surface). No errors were committed by the control group for either the DL/FI or DL/FO tests. One subject in the MHI group committed an error during the DL/FI test. Asterisk indicates significant difference from other group.

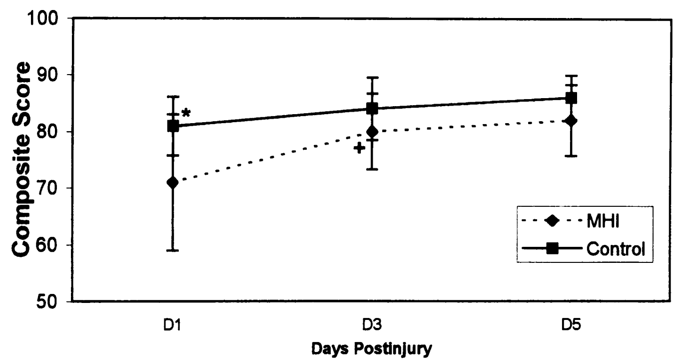

Figure 7. Composite score means (±SD) on the NeuroCom Smart Balance Master for each testing session (day 1 postinjury through day 5 postinjury). Asterisk indicates significant difference from other group; +, significant difference from day 1 test. Tukey HSD = 5.28, *P* < .05.

comparisons are not possible, and the large variations in signs and symptoms can make clinical judgments difficult. Thus, the most effective use of any objective measure available for MHI assessment involves comparing an individual's postinjury scores with those recorded at a baseline session. If baseline scores are not available, clinicians might consider using the means and standard deviations reported in Table 3 as guides for comparison in an athletic population.

The challenge to develop objective MHI assessment procedures has been undertaken by several disciplines, including neurosurgery, neuropsychology, family practice, and pediatrics.[11,19,23–26] We should not rely solely on only 1 assessment approach, such as postural control or cognition, but should instead consider all available methods. The pathophysiology of MHI is complex and can be expected to affect each individual differently. For example, we have witnessed several athletes who exhibit momentary unconsciousness, but fail to display postural instability or cognitive deficits. Clinicians with return-to-play decision responsibilities should, therefore, remain abreast of MHI-related research and developments, incorporating all available approaches into their assessment protocols.

Return-to-play guidelines have been proposed based on loss of consciousness and symptom resolution.[11,19,24] Although these guidelines provide for convenient grading systems, their bases for return-to-play timing are not objective scientific data. In addition, the underlying basis for return-to-play timing in the absence of loss of consciousness is symptom resolution. Many athletes may not understand the seriousness of MHI and may be inclined to deny the presence of symptoms in hopes of a more timely return. It is imperative that clinicians use guidelines for their original purpose, as guides, and make their final decisions with considerations to loss of consciousness, resolution of symptoms, and the results of objective testing procedures.

CONCLUSIONS

The results of our investigation are applicable to all clinicians with return-to-play decision responsibility. We propose that a battery of stances (double leg, single leg, and tandem) on a foam surface in conjunction with the BESS may be useful for identifying postural instability after MHI in the absence of sophisticated balance equipment. In addition, these results suggest an objective procedure that could be used in sideline evaluations; however, further research is warranted. Relying solely on postural stability for MHI assessment is not recommended. As previously mentioned, MHI is a complex pathology, and unique individual responses can be expected. Efforts should be made to consider both subjective symptoms and other objective measures, such as cognitive testing, before making return-to-play decisions.

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